PATENT SPECIFICATION

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PROVISIONAL SPECIFICATION
No. 13450, A.D. 1946

Improvements in and relating to Hydraulic Pumps and Motors

We, ELECTRAULIC PRESSES LIMITED, a British Company, of Electraulic Works, Rodley, near Leeds, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention relates to hydraulic multi-ram pumps of the kind having a cylinder block in which the pump rams and associated cylinder bores are disposed around and parallel with a common axis, and in which the rams are reciprocated by means of a swash-plate or wobble plate, or similar device in which a flat plate or disc is given angular oscillation in two planes in relation to the axes of the rams by the rotation of the driving shaft. It will be understood that the cylinder block may be in one piece, or it may comprise a number of cylinder blocks secured together and forming one assembly. It will be further understood that if a pump of this construction is supplied with pressure fluid and provided with suitable valve gear it will operate as a rotary motor, to which this invention may be applied with equal facility.

One object of this invention is to control the relative rotational displacement between the wobble plate and the cylinder block. For instance in a pump of the kind described above, in which connecting rods are interposed between the rams and the wobble plate, it is essential that there should be no appreciable rotational displacement between the cylinder block and the wobble plate. On the other hand in a pump of the type described above, in which the ram ends make direct contact with the wobble plate, it is desirable that the wobble plate should have rotational displacement relative to the cylinder block such as to ensure that there shall be approximately pure rolling contact between the ram ends and the wobble plate.

A further object of this invention is to provide a pump of simple construction, in which the component parts shall be readily accessible and capable of being driven at high speeds in the region of 1500 R.P.M., and capable of high pressures in the region of 7000 p.s.i., and having a volumetric efficiency of 95—97% throughout the pressure range. It will be appreciated that the above performance may not be entirely achieved, or it may be surpassed, and experiments are being carried out to ascertain the best conditions to ensure a high performance.

Pumps such as described above may be divided into two distinct types: one in which the driving shaft is co-axial with the axis of the cylinder block, and the other in which the driving shaft is at an oblique angle to the axis of the cylinder block. In the co-axial type of pump the wobble plate or swash plate is supported on a swash member set at an oblique angle to the driving shaft, or the wobble plate may be supported by a **Z** crank at an oblique angle to the driving shaft, or the wobble plate may be pivotally supported and actuated by a crank. The co-axial type of pump may be further sub-divided into two types: one in which the cylinder block rotates with the driving shaft, and the other in which the cylinder block is stationary. In the type in which the cylinder block rotates with the shaft, the swash member or **Z** crank remains stationary, and the wobble plate rotates with the cylinder block. In the other type in which the cylinder block is stationary the swash plate or **Z** crank rotates with the shaft, and the wobble plate remains stationary if connecting rods are interposed between the pump rams and the wobble plate, or the wobble plate has a comparatively small rotational displacement relative to the cylinder block

if the pump ram ends make contact with the wobble plate. In the other distinct type of pump in which the driving shaft is set at an oblique angle to the axis of the cylinder block, the cylinder block rotates with the driving shaft, and the wobble plate is supported by the driving shaft with the face of the wobble plate normal to the axis of the driving shaft. In the latter type of pump if connecting rods are interposed between the pump rams and the wobble plate then the wobble plate must rotate with the cylinder block, but if it is of the type in which the ram ends make contact with the wobble plate then it is desirable that there should be a comparatively small rotational displacement between the wobble plate and the cylinder block in order to ensure that there shall be approximately pure rolling contact between the ram ends and the wobble plate. In one well known construction of the latter type of pump it is the practice to transmit the drive between the oblique driving shaft and the cylinder block by means of a double ball and socket joint, but this has the disadvantage that, whether the mechanism is operated as a pump or as a motor, the double ball and socket joint has to transmit about half the driving or driven torque. In all the constructions described above it is the practice to provide anti-friction bearings to take the thrust of the wobble plate.

Thus broadly, this invention may be applied with equal facility to any of the above constructions of pump or motor and it consists in providing a positive drive between the wobble plate and the cylinder block by means of either toothed gearing or friction gearing with the object of maintaining the correct rotational displacement between the wobble plate and the cylinder block such that if connecting rods are interposed between the pump rams and the wobble plate there shall be no rotational displacement between the wobble plate and the cylinder block, and alternatively, if the ram ends make contact with the wobble plate or if push rods associated with the pump rams make contact with the wobble plate, there shall be continuous rotational displacement between the wobble plate and the cylinder block such as to ensure approximately pure rolling contact between the ram ends or push rod ends and the wobble plate. It will be appreciated that in some constructions the torque transmitted by the above described toothed gearing or friction gearing may be comparatively light, because its sole function is to maintain correct rotational displacement between the wobble plate and the cylinder block, and it only has to overcome the frictional torque between the wobble plate and its supporting anti-friction bearings, and in a pump employing connecting rods there may be an additional transverse component due to the angularity of the connecting rods, but in any case the torque will be a very small proportion of that of the driving shaft, but in other constructions the said gearing may be arranged to transmit the whole of the driving torque without departing from this invention.

One embodiment of this invention consists of a hydraulic multi-ram pump for pumping oil having a stationary cylinder block, in which the pump rams and associated cylinder bores are equally spaced and disposed symmetrically around and parallel with a common axis co-axial with the driving shaft. The rams are reciprocated by means of a wobble plate which is supported by a swash member set at a fixed angle and secured to the driving shaft, so that in this embodiment the stroke of the pump rams is not variable. Suitable anti-friction bearings are provided between the wobble plate and the swash member so as to take the thrust of the pump rams normal to the oblique face of the swash member; and anti-friction bearings are provided to take the thrust between the transverse face of the swash member and the end of the pump casing normal to the driving shaft; and suitable journal bearings are provided to support the driving shaft and take care of the angular component of the thrust of the pump rams. The cylinder block is rectangular and the cylinder bores are of the type described and illustrated in British Patent Application No. 489,691, in which each pump ram almost completely fills its bore at the inner end of each discharge stroke, and provided with mushroom type inlet and delivery valves. The inlet valve is at the inner end of and co-axial with the pump bore, and the valve stem is suitably guided and provided with inlet passages parallel to the valve stem and communicating with the transverse face of the cylinder block remote from the pump rams. A hollow rectangular cover is secured to the latter or rear face of the cylinder block and serves as an inlet manifold, and a small booster pump is provided to supply oil at a pressure of about 50 pounds per square inch to the inlet manifold and of a capacity exceeding the maximum delivery of the pump, sufficient to maintain the pump rams in contact with the wobble plate. The four faces of the rectangular cylinder block, parallel with the axes of the pump rams, are bored to receive the

delivery valves and delivery valve caps, the delivery valve stems extending outwards in one transverse plane with their axes normal to the face of the rectangular cylinder block nearest to their associated cylinder bores. The cylinder block is drilled from four sides and suitably plugged to form a rectangular manifold communicating with the delivery chambers above each delivery valve and connected to the delivery outlet of the pump. The other transverse face of the cylinder block, out of which the pump rams protrude, which will be referred to as the front face, is secured to a casing which contains the driving shaft and wobble plate. The end of the driving shaft opposing the pump rams has an oblique face which will be referred to as the swash member, and a suitable anti-friction bearing is provided to take the thrust between the swash member and the end of the pump casing normal to the driving shaft, and suitable journal bearings are provided to support the driving shaft and to take care of the angular component of the thrust of the pump rams. The wobble plate is mounted on the oblique face of the swash member and suitable anti-friction bearings are provided between the wobble plate and the swash member. The pump ram ends, which bear against the flat face of the wobble plate, are convex and spherically shaped with the centre of curvature at all times within the cylinder bore and so arranged as to provide the minimum offset loading between the pump rams and cylinder bores throughout the delivery or discharge stroke, and the rams are free to rotate within their associated bores. A bevel wheel is secured to or integral with the periphery of the wobble plate and meshes with a crown wheel secured to or integral with the front face of the cylinder block. The ratio of the number of teeth in the bevel wheel and the number of teeth in the crown wheel is such as to ensure that there shall be approximately pure rolling contact between the pump ram ends and the flat face of the wobble plate, which is at all times parallel to the oblique face of the swash member. So far as we have been able to ascertain this ratio is equal to the secant of the angle between the oblique face of the swash member and a plane normal to the ram axes, and the rotational displacement of the wobble plate in relation to the cylinder block is in a reverse direction to the rotation of the driving shaft. As already mentioned, a small gear pump or other type of booster pump driven off the pump driving shaft is provided to maintain an inlet pressure sufficient to hold the pump rams in contact with the wobble plate on their outward stroke, and the inward or delivery stroke, or discharge stroke, is effected by the wobble plate.

A further embodiment of this invention consists of a hydraulic multi-ram pump in which the cylinder block is stationary and generally constructed as described in the previous embodiment, except that connecting rods are interposed between the pump rams and the wobble plate, and the ratio between the bevel and crown wheel gears is unity, so as to ensure that there shall be no rotational displacement between the wobble plate and the cylinder block.

It will be understood that if connecting rods are used, or if springs are provided to effect the outward stroke of the pump, rams, the booster pump may be dispensed with without departing from this invention.

Another embodiment of this invention consists of a hydraulic multi-ram pump or motor generally constructed as described and illustrated in British Patent No. 380,578, excepting that the double ball and socket joint, to transmit the drive between the cylinder block and the driving shaft is replaced by toothed gearing by means of which the cylinder block and the wobble plate and shaft are caused to rotate at the same speed, and characterised in that the axis of the driving shaft is set at a fixed angle to the axis of the cylinder block, so that there is no variation in the stroke of the rams or pistons.

Yet a further embodiment of this invention consists of a hydraulic multi-ram pump or motor generally constructed as described and illustrated in British Patent No. 380,578, excepting that the axis of the driving shaft is set at a fixed angle to the axis of the cylinder block so that there is no variation in the length of stroke, and the pistons and connecting rods are replaced by rams having convex spherically curved ends which are held in contact with the wobble plate by means of springs or by liquid pressure, and the double ball and socket joint is replaced by toothed gearing of such a ratio as to ensure continuous rotational displacement between the wobble plate and the cylinder block such as to ensure that there shall be approximately pure rolling contact between the ram ends and the surface of the wobble plate.

In all the above embodiments the wobble plate is set at a fixed angle to the axis of the cylinder block and therefore the length of stroke of the rams or pistons is not variable. This invention may be

applied to a variable stroke pump or motor of any of the constructions broadly described above, in which connecting rods are employed, by varying the angle of the wobble plate about an axis which ensures that the toothed gearing between the wobble plate and the cylinder block remains in mesh and has a ratio of unity; or, if the ram ends make contact with the wobble plate, friction gearing may be employed between the wobble plate and the cylinder block and so arranged that the gear ratio varies with and is always approximately equal to the secant of the tilting angle.

Although the pump rams and associated bores have been described as being parallel with a common axis as indicating the type of pump or motor to which this invention applies, it will be understood that the rams and associated cylinder bores may be inclined at a slight angle to the common axis without departing from this invention.

Dated this 30th day of April, 1946.

PROVISIONAL SPECIFICATION.
No. 18087, A.D. 1946

Improvements in and relating to Axial Type Reciprocating Pumps, Compressors, Motors and Engines

We, Electraulic Presses Limited, a British Company, of Electraulic Works, Rodley, near Leeds, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention relates to axial type reciprocating pumps, compressors, motors and engines of the kind in which the pistons or rams are disposed around and parallel with a common axis and reciprocated by means of a swash plate or wobble plate or similar device in which a flat plate or disc is given angular oscillation in two planes in relation to the axes of the pistons or rams by the rotation of the driving shaft. For the purpose of description, the said flat plate or disc will be referred to hereafter as the wobble plate, and the face of the shaft which supports the wobble plate will be referred to as the swash member.

Pumps, compressors, motors and engines of the type described above are of very compact construction and the principal difficulty has been to provide suitable anti-friction bearings to withstand the axial thrust of the pistons or rams within the confined space available. One object of this invention is to provide improved anti-friction means for transmitting the axial thrust between the pistons or rams and the wobble plate. A further object of this invention is to provide improved anti-friction means to transmit the thrust between the wobble plate and the swash member. Yet a further object of this invention is to provide improved anti-friction means to take care of the axial thrust of the driving shaft in addition to the turning moment normal to axis of the shaft due to the angularity of the wobble plate. A further general object of this invention is to provide improved anti-friction means for transmitting axial thrust whereby pumps, compressors, motors and engines of the type described may be operated at comparatively high speeds, exceeding one thousand revolutions per minute, and at higher fluid pressures than have been hitherto practicable.

One embodiment of this invention consists of an axial type hydraulic multi-ram pump for pumping oil having a stationary cylinder block in which the pump rams and associated cylinder bores are equally spaced and disposed symmetrically around and parallel with a common axis, co-axial with the driving shaft. The rams are reciprocated by means of a wobble plate which is supported by a swash member set at a fixed angle and secured to the driving shaft, so that in this embodiment the stroke of the pump rams is not variable. Anti-friction bearings are provided between the wobble plate and the swash member, and further anti-friction bearings are provided to support the driving shaft. These anti-friction bearings are of an improved type and will be described later. The cylinder block is rectangular and the cylinder bores are of the type described and illustrated in British Patent Application No. 489,691 in which each pump ram almost completely fills its bore at the inner end of each discharge stroke and provided with mushroom type inlet and delivery valves. The inlet valve is at the inner end of and co-axial with the pump bore, and the valve stem is suitably guided and provided with inlet passages parallel to the valve stem and communicating with the transverse face of the cylinder block remote from the pump rams. A hollow rectangular cover is secured to the latter or rear face of the cylinder block and serves as an inlet manifold, and a small booster pump is provided to supply oil at a pressure of about 50 lbs. per square inch

to the inlet manifold and of a capacity exceeding the maximum delivery of the pump sufficient to maintain the pump rams in contact with the wobble plate. The four faces of the rectangular cylinder block parallel with the axes of the pump rams are bored to receive the delivery valves and delivery valve caps, the delivery valve stems extending outwards in one transverse plane with their axes normal to the face of the rectangular cylinder block nearest to their associated cylinder bores. The cylinder block is drilled from four sides and suitably plugged to form a rectangular manifold communicating with the delivery chambers above each delivery valve and connected to the delivery outlet of the pump. The other transverse face of the cylinder block out of which the pump rams protrude, which will be referred to as the front face, is secured to a casing which contains the driving shaft and wobble plate. The end of the driving shaft opposing the pump rams has an oblique face which forms the swash member, and the wobble plate is mounted on a pintle in the centre of the swash member so that it rotates about an axis normal to the said oblique face. The axis of the wobble plate intersects the axis of the driving shaft at a point which coincides with the centre of oscillation of the plane of contact between the ram ends and the wobble plate, so that in fact the wobble plate is free to rotate about the centre of oscillation. The pump ram ends which bear against the flat face of the wobble plate are convex and spherically shaped with the centre of curvature at all times within the cylinder bore and so arranged as to provide the minimum offset loading between the pump rams and the cylinder bores throughout the delivery or discharge stroke and the rams are free to rotate within their associated bores. A bevel wheel is secured to or integral with the periphery of the wobble plate and meshes with a crown wheel secured to or integral with the front face of the cylinder block. The ratio of the number of teeth in the bevel wheel and the number of teeth in the crown wheel is such as to ensure that there shall be approximately pure rolling contact between the pump ram ends and the flat face of the wobble plate, which is parallel to the oblique face of the swash member. So far as we have been able to ascertain this ratio is equal to the secant of the angle of the oblique face of the swash member to a plane normal to the axes of the rams, and the rotational displacement of the wobble plate in relation to the cylinder block is in a reverse direction to the rotation of the driving shaft. As already mentioned, a small gear pump or other type of booster pump driven off the pump driving shaft is provided to maintain an inlet pressure sufficient to hold the pump rams in contact with the wobble plate on their outward stroke, and the inward or delivery stroke is effected by the wobble plate. The pump rams are of hardened steel and the surface of the wobble plate with which they make contact is also of hardened steel. The surface of the wobble plate opposed to the swash member is also of hardened steel, and an anti-friction bearing is interposed between the wobble plate and the swash member. The anti-friction bearing consists of a circular mild steel washer mounted on the pintle which supports the wobble plate, and it is prevented from rotating in relation to the swash member by means of a small pin or key. The mild steel washer is faced with white metal on the side opposing the wobble plate and it is provided with a number of radial grooves and suitable means are provided to ensure that an adequate supply of oil from the driving shaft casing is free to flow along the shaft to the inner end of each groove and outwards across the face of the bearing. The pump rams are only very lightly loaded on the suction stroke due to the pressure of the booster pump, and therefore it is only on the discharge stroke that the axial ram load is severe. Consequently the anti-friction bearing is eccentrically loaded. The result is that the face of the washer which opposes the rams making their discharge stroke is subject to high pressure and the face of the washer opposed to the rams making their suction stroke is subject to very low pressure, and this condition appears to be favourable to the creation of what is termed " pressure film lubrication ". A similar anti-friction bearing is provided between the rear face of the swash member, which is normal to the axis of the shaft, and the end of the driving shaft casing. That is to say that a similar washer is mounted on the rear face of the swash member and prevented from rotating in relation to the swash member by means of a small pin or key; the said washer is opposed by a relatively thick hardened steel ring of approximately the same annular area as the washer and mounted in the end of the driving shaft casing and prevented from rotating relative to the casing; the surface of the washer opposed to the ring is faced with white metal and provided with radial grooves suitably supplied with lubricating oil from the shaft casing. A single ball bearing journal is provided in the end of the shaft casing to support the shaft,

but the shaft is axially free so that the above described thrust washer alone takes care of the turning moment normal to the axis of the shaft due to the angularity of the wobble plate. Furthermore the shaft is driven by means of a carden type flexible coupling so that the shaft is not subject to serious external force tending to axial displacement or misalignment. From experiments which we have made it appears that a pump of this construction will operate satisfactorily at 1500 revolutions per minute when pumping against pressures exceeding 10,000 pounds per square inch and with a mean pressure on the annular area of the anti-friction washers in the region of 1000 pounds per square inch. The maximum pressure of the oil film is probably in the region of 2000 to 3000 pounds per square inch and experiments are being made to determine the degree of eccentricity of load which will provide optimum load bearing capacity.

A further embodiment of this invention consists of an axial type hydraulic multi-ram pump for pumping oil generally as described in the first embodiment, excepting that the anti-friction washers are dispensed with and the rear face of the wobble plate bears directly against the oblique face of the swash member and the rear face of the swash members bears directly against the surface of the thrust ring in the end of the driving shaft casing. In this construction the swash member is made of gun metal or it may be made of mild steel faced with white metal. Radial oil grooves are provided in the hardened faces of the wobble plate and the thrust ring in the end of the driving shaft casing. The function of the anti-friction bearings is the same and in fact this construction simply comprises making the anti-friction washers integral with the swash member.

According to this invention one essential feature of the above described anti-friction bearings between the swash member and the wobble plate, and between the swash member and the end of the driving shaft casing, is that they comprise opposed plane surfaces subject to relative rotation at comparatively high surface speed and with the load eccentric to the axis of rotation to an extent, with or without an additional turning moment normal to the axis of rotation, such that there is a pressure gradient across the opposing surfaces varying from a very low pressure approaching zero at one part of the perimeter to a maximum pressure at the diametrically opposite part of the perimeter and the alignment of the opposed surfaces is constrained solely by the pressure and thickness of the oil film created between them. That is to say that the opposing surfaces are not operatively parallel but they are free to form a wedge with the lubricating oil film between them, the said wedge being diametrically across the opposed surfaces. The latter distinguishes it from a Michell type thrust bearing consisting of a number of segments bearing against a thrust collar on the shaft each of which tends to form a wedge with the lubricating oil film at a tangent to the rotating collar.

A further feature of this invention is the provision of improved means for transmitting the axial thrust between the pistons or rams and the wobble plate such that there shall be approximately pure rolling contact between the piston rod ends or ram ends and the surface of the wobble plate, generally as described in the first embodiment. It will be understood that according to this invention the above features may be used separately or in combination. For instance in some embodiments of this invention we may prefer to use connecting rods to transmit the thrust between the pistons or rams and the wobble plate in combination with the above described anti-friction bearings between the wobble plate and the swash member and between the swash member and the end of the driving shaft casing. In such embodiments it will be necessary to provide means to ensure that there is no rotational displacement between the wobble plate and the body containing the pistons or rams, and this may be done by employing bevel and crown gears having a ratio of unity, or by other known means. It will be uderstood that if connecting rods are used or if springs are provided to maintain contact between the piston rod ends or ram ends and the surface of the wobble plate the booster pump may be dispensed with without departing from this invention. Also when the invention is applied to motors or engines it is probable that the booster pump will not be required because the fluid pressure will maintain the piston rod ends or ram ends in contact with the wobble plate.

In the first embodiment described above, the driving shaft is co-axial with the common axis of the pump rams. In another well known construction of axial type hydraulic pump or motor the axis of the driving shaft is at an angle to the common axis of the pistons or rams and the face of the swash member is transverse to the axis of the driving shaft. It will be understood that this invention may be applied with equal facility to a pump or motor of the latter construction.

invention may be applied with equal facility to almost any known construction of axial type reciprocating pump, compressor, motor or engine. It will be further understood that this

Dated this 14th day of June, 1946.

PROVISIONAL SPECIFICATION
No. 19839, A.D. 1946

Improvements in and relating to Axial Type Reciprocating Pumps, Compressors, Motors and Engines

We, ELECTRAULIC PRESSES LIMITED, a British Company, of Electraulic Works, Rodley, near Leeds, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention relates to axial type reciprocating pumps, compressors, motors and engines, of the kind described in our co-pending British Patent Application No. 18087 of June 17th, 1946. According to the said application one essential feature of the anti-friction bearings between the swash member and the wobble plate, and between the swash member and the end of of the driving shaft casing, described therein, is that they comprise opposed plane surfaces subject to relative rotation at comparatively high surface speed and with the load eccentric to the axis of rotation to an extent, with or without an additional turning moment normal to the axis of rotation, such that there is a pressure gradient across the opposing surfaces varying from a very low pressure approaching zero at one part of the perimeter to a maximum pressure at the diametrically opposite part of the perimeter, and the alignment of the opposed surfaces is constrained solely by the pressure and thickness of the oil film created between them. It will be appreciated that the pressure of the oil film will tend to force the opposed surfaces apart and, as the intensity of pressure is at a maximum at a part of the perimeter, it may cause the surfaces to become concave due to flexure, and this flexure may be further accentuated by the high temperatures of the opposing surfaces. If the thrust load is small, or if the opposed members are very robust or very rigidly supported, this flexure may be negligible. On the other hand, if the thrust load is heavy or one of the opposed members is comparatively thin, or inadequately or badly supported, the flexure may be such as to prevent the creation of an effective pressure film of oil between the surfaces, and consequently they will come into contact. In the latter case, in order to counteract the effect of flexure, one or both of the opposed surfaces may be made slightly concave in accordance with this invention. For instance with reference to the wobble plate described in the first embodiment of our co-pending Application No. 18087 of June 17th, 1946, in which the plate is comparatively thin and the load is applied near the centre, we have found it necessary to make the surface opposed to the swash member slightly concave, of the order of one thousandth of an inch at the centre of a diameter of three inches, in order to ensure a high load bearing capacity. In the said embodiment the load is applied near the centre of the wobble plate by the ram ends which make contact with the plate at a radius of less than half that of the perimeter of the opposed surfaces; and the pressure of the oil film between the opposed surfaces is thought to be at a maximum along a part of the perimeter; consequently there is flexure of the plate due to the pressure and temperature of the oil film and we make the surface concave to allow for this flexure.

It will be seen therefore that it is a feature of this invention that the opposed surfaces are so supported and/or so shaped and the load is so applied that they comprise operatively plane surfaces when subject to the pressure and temperature of the oil film created between them at maximum load bearing capacity, the object being to prevent the opposed surfaces coming into contact.

Dated this 1st day of July, 1946.

COMPLETE SPECIFICATION

Improvements in and relating to Axial Type Reciprocating Pumps, Compressors, Motors and Engines

We, ELECTRAULIC PRESSES LIMITED, a British Company, of Electraulic Works, Rodley, near Leeds, Yorkshire, do hereby declare the nature of thi invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

This invention relates to hydraulic multi-ram pumps of the kind having a cylinder block in which the pump rams and associated cylinder bores are disposed

around a common axis the rams being reciprocated either directly or through push rods without the interposition of connecting rods by means of a ram actuating device comprising a wobble plate which is usually in the form of a flat plate or disc and is given angular oscillation in two planes in relation to the axes of the rams, such oscillation being produced either by supporting the ram actuating member on a swash member or "Z" crank hereinafter termed a swash member—the cylinder block in this case being stationary—or by rotating the cylinder block and a ram actuating device each about its own axis, the two axes intersecting at an oblique angle. In this latter case, either the cylinder block or the ram actuating device may be directly coupled to the driving shaft, power being positively transmitted through gearing either from the cylinder block to the ram actuating device or *vice versa* and in these cases the ram actuating device will be a non-oscillating member. The above description is to be read as a definition of the term "of the type specified", used in the claims at the end of this specification. It will be understood that the cylinder block may be in one piece, or it may comprise a number of cylinder blocks secured together and forming one assembly. It will be further understood that if a pump of this construction is supplied with pressure liquid and provided with suitable valve gear it will operate as a rotary motor, to which this invention may be applied with equal facility and the term "pump" hereinafter used in this specification is to be read as including a motor.

The object of the present invention is to minimise or avoid skidding or slipping between the ram ends and the contacted surface of the actuating device in a pump of the type above specified.

Broadly the present invention consists of an hydraulic multi-ram pump of the type specified in which the contacted ends of the rams or push rods are free to turn when twisted, such as by the relative motion of the ram actuating device, and in which the actuating device is connected positively to the cylinder block by toothed gear having a tooth ratio such as will cause the part of the ram actuating device which is contacted by the rams to have a predetermined rotational displacement in relation to the cylinder block and which does not exceed to any substantial extent the secant of the angle of the face of the ram actuating device to a plane normal to the axes of the rams.

In a preferred embodiment of the invention the ideal tooth ratio is one which is equal to the secant of the angle of the face of the ram actuating device to a plane normal to the axes of the rams, but in no instance must the tooth ratio exceed a ratio equal to the square of the secant of the angle of the face of the ram actuating device to a plane normal to the axes of the rams.

The parts of the pump in the preferred embodiment where the ideal tooth ratio is employed should be arranged so that the point of intersection of the axis of the ram actuating device and the axis of the cylinder block lies in the pitch plane of a crown wheel on the cylinder block and coincides with the apex of the pitch cone of a bevel wheel on the ram actuating device.

The gear connection of the present invention effectively removes the necessity of providing frictionless bearings and in consequence we are enabled to use plain bearings capable of carrying the highest thrust loads likely to be met with in practice, which affords the added advantage that the size and cost of the pump is considerably less than would be possible with ball or roller bearings. A suitable thrust bearing for a pump according to the present invention is one comprising two plane and relatively rotatable opposed surfaces which are held out of metal to metal contact by an interposed film of oil. If necessary the effect of surface flexure in such a bearing may be counteracted by making one or both opposed surfaces slightly concave, for example, one thousandth of an inch at the centre of a diameter of three inches. Alternatively the thrust bearing may be supported on an annular surface having a diameter intermediate the inner and outer diameters of an annular thrust washer.

With such a bearing we have been able, under test, satisfactorily to operate an axial type reciprocating pump at delivery pressures approaching 15,000 pounds per square inch.

It is supposed but not actually proved that if a relative tilt is permitted between the opposing surfaces in a bearing of the above kind and if the load is eccentric to the axis of the bearing the opposing surfaces will not be operatively parallel but will be forced by the oil film to form between them a space of wedge-like form extending across the opposed surfaces said oil film acting to hold the two surfaces out of metal to metal contact.

In a pump according to the present invention, in its preferred construction, the cylinder block is stationary and the ram actuating member is contacted on one face by the ram ends or push rods and is

supported on the other face against the axial thrust of the rams by the inclined face of the swash member through an interposed axial thrust bearing as previously described.

In order that the invention may be clearly understood and carried into effect three embodiments of the same will now be described, by way of example, by aid of the accompanying drawings in which:

Fig. 1 is a sectional elevation through the preferred embodiment in which the cylinder block is stationary and arranged with its axis coincident with the axis of the drving shaft for a ram actuating device which consists of a "Z" crank or swash member on which is mounted a wobbler.

Fig. 2 is a sectional perspective view of the pump shown in Fig. 1.

Fig. 3 is a part sectional elevation of a portion of the pump shown in Fig. 1 illustrating the swash member, wobbler and gear connection and showing to a greatly exaggerated scale supposedly formed wedge-shaped gaps containing the oil films of the two thrust bearings on both sides of the swash member, the gap between the wobbler and the swash member being indicated by the reference letter A and the other gap on the opposite side of the swash member by the reference letter B.

Fig. 4 is a diagrammatic sectional elevation of an embodiment in which both the cylinder block and ram actuating device revolve and in which the driving shaft is coupled directly to the ram actuating device, the cylinder block being driven from the latter through tooth gear in the form of an inter-meshing crown and bevel wheel.

Fig. 5 is a diagrammatic sectional elevation of an embodiment which is similar in every way to Fig. 4 except that the driving shaft is coupled directly to the cylinder block and the ram actuating device is driven from the cylinder block by tooth gear in the form of inter-meshing crown and bevel wheels.

The axial pump illustrated in Figs. 1 and 2 of the drawings comprises a casing 1 for a motor which is connected by a flexible coupling to a driving shaft 2 having at its lower end an enlarged boss formed with an oblique lower face 3, the whole constituting the swash member which is referred to generally by the numeral 4. Supported by the oblique face 3 of the swash member is the wobbler 5. This wobbler is free to tilt in relation to the oblique face of the swash member and is, for preference, made wholly of hardened steel, or, in the larger sizes, the upper and lower faces thereof are hardened, and around the peripheral edge of the lower face are cut, or there is otherwise provided, a series of teeth to form a bevel wheel 6 which meshes with a crown wheel 7 that is secured to or formed integral with the upper face of the cylinder block 8.

The cylinder block 8 in this example is stationary and is bored to provide six or other required number of cylinders 9. These cylinders are arranged symmetrically and at equal distances from each other around the vertical axis of the pump and each is provided with a ground and freely rotatable and reciprocable plunger 10. The inlet and discharge openings and valves for each cylinder are in the example illustrated arranged in the manner described in our Patent Specification No. 489,691, that is each pump ram almost completely fills its bore or cylinder at the end of the discharge stroke whilst the inlet valve 9*a* is arranged at the inner end co-axial with its bore or cylinder and the delivery outlet 9*b* in the side wall thereof as close as possible to the lower end of the bore or cylinder. The stem of each inlet valve is suitably guided and a series of inlet passages 11 are provided, said passages communicating with a chamber 12 common to all of them which chamber is maintained full of oil.

The pump ram ends which bear against the opposing face of the ram actuating member are convex and spherically or conically shaped with the centre of curvature or centre of thrust at all times within the cylinder bores so as to ensure the minimum offset loading between the pump rams and their bores throughout the delivery or discharge strokes.

To maintain an inlet pressure within the chamber 12 sufficient to hold the pump rams in contact with the wobbler on their outward stroke there is provided a gear pump 13 serving as a booster pump and this pump is driven from the main driving shaft 2 by means of an axial secondary shaft 14, the connection between said secondary shaft and the main shaft 15 of the gear pump consisting of a flexible coupling 15*a*, both said shafts having freedom for axial movement.

Alternatively, instead of or in addition to employing a flexible coupling which permits the swash member to be free to tilt, the booster pump driving shaft may be made flexible.

In the example illustrated the rear face of the wobbler bears directly against the oblique face of the swash member and the rear face of the swash member bears directly against the surface of a hardened

steel thrust ring 16 which in turn seats against the underside of the outer ring of a ball or roller bearing journal 17.

The use of a single ball or roller bearing journal 17, intermediate the length of the shaft 2, in conjunction with a flexible coupling 18 for the upper end of said shaft on a sufficiently flexible shaft permits the swash member 4 to have limited freedom to tilt sufficient to permit the same either to seat squarely against the thrust ring 16 or to tilt under the offset load so that the opposing surfaces are then held out of actual metal to metal contact by a wedge-shaped film of oil.

In this construction the swash member may be made of gun metal or it may be made of mild steel faced with white metal. Alternatively the surface of the swash member may be hardened steel and the rear face of the wobbler may be faced with white metal and the surface of the thrust ring also faced with white metal. As far as we have been able to ascertain the soft surface should be the surface in relation to which the load is stationary. In the case of a pump with a stationary pump body the soft surface should rotate.

If desired the thrust bearing between the swash member and the wobbler may consist of a white metal faced circular mild steel washer which is pinned to prevent the same from rotating in relation to the swash member.

Radial oil grooves 19 are provided in the faces of the swash member and radial holes 20 are provided in the wobbler and thrust ring to permit oil to gain access to spaces 21 and 22, the space 21 being between the wobbler and a pintle 23 on the underside of the swash member on which the wobbler is mounted so as to be free to rock in relation to the oblique supporting face of the swash member and the other space 22 being between the thrust ring and the driving shaft 2. A continuous supply of oil is thus available at the inner ends of the grooves along which it is propelled by centrifugal action due to the rotation of the shaft. Oil from space 22 is free to circulate through the thrust ring 16 and ball or roller bearing 17 and any excess oil is permitted to escape through the valve controlled outlet 24.

It will be appreciated that the pressure of the oil film will tend to force the opposed surfaces of the thrust bearings apart, and as the intensity of pressure is at a maximum at a part of the perimeter it may cause the surfaces to become convex due to flexure, and this flexure may be further accentuated by the high temperature of the opposing surfaces. If the thrust load is small, or if the opposed members are very robust or very rigidly supported, this flexure may be negligible. On the other hand, if the thrust load is heavy or one of the opposed members is comparatively thin, or inadequately or badly supported, the flexure may be such as to prevent the creation of an effective pressure film of oil between the surfaces, and consequently they will come into contact. In the latter case, in order to counteract the effect of flexure, one or both of the opposed surfaces may be made slightly concave. For instance with reference to the wobbler herein described in which the plate is comparatively thin and the load is applied near the centre, we have found it necessary to make the surface opposed to the swash member slightly concave, of the order of one thousandth of an inch at the centre of a diameter of three inches, in order to ensure a high load bearing capacity. In the said embodiment the load is applied near the centre of the wobblers by the ram ends which make contact with the wobbler at a radius of less than half that of the radius of the perimeter of the opposed surfaces; and the pressure of the oil film between the opposed surfaces is thought to be at a maximum nearer the perimeter; consequently there is a flexure of the wobbler due to the pressure and temperature of the oil film and we make the surface concave to allow for this flexure.

The annular thrust washer 16 may be supported on an annular surface having a diameter intermediate its inner and outer diameters.

It will be seen therefore that the opposed surfaces are so supported and/or so shaped and the load is so applied that when subject to the pressure and temperature of the oil film created between them at maximum load bearing capacity, they are prevented from coming into contact.

It will be understood that if springs are provided to maintain contact between the ram ends and the surface of the ram actuating device the booster pump may be dispensed with without departing from this invention. Also when the invention is applied to motors or engines booster pumps will not be required because the fluid pressure will maintain the ram ends in contact with the wobble plate.

In the preferred example just described the cylinder block is stationary but it is a simple matter to apply the invention to a design in which the cylinder block is rotated.

The invention is also applicable to that type of axial reciprocating ram pump in which the axis of the driving shaft is at

an angle to the common axis of the cylinder block and the face of the ram actuating device is transverse to the axis of the driving shaft.

Examples of both such embodiments are shown in the accompanying drawings and will now be described.

In Fig. 4 there is illustrated the embodiment in which the driving shaft drives the actuating device directly the axis of the driving shaft being at an angle to the common axis of the cylinder block. Also both the cylinder block 8 and the ram actuating device revolve, the driving connection between the two consisting of toothed gearing as in Fig. 1 in the form of intermeshing bevel wheels 6 and 7 so that the cylinder block is driven directly through the gearing. In this example, as in the example illustrated in Figs. 1 and 2, the actuating device is supported against thrust by a thrust washer or reaction plate 16 and the said actuating device is also mounted so as to be free to tilt in relation to the thrust washer.

In the present embodiment rams 10 are employed similarly to the embodiment shown in Figs. 1 and 2, and the convex ends of these rams make direct contact with the opposing face of the actuating device, which in this example is transverse to the axis of its rotation. As there is relative rotational displacement between the actuating device and the cylinder block so the ratio between the number of teeth in the two members of the gear connection is equal to or substantially equal to the secant of the angle of the face of the actuating device to a plane normal to the axes of the rams and such that the rotational displacement of the ram actuating device is in the same direction as the rotation of the cylinder block but slightly faster.

The embodiment illustrated in Fig. 5 shows the application of the invention to a design in which both the actuating device and the cylinder block revolve, the cylinder block being positively or directly driven through the integral or attached shaft 2 and the actuating device being driven by the cylinder block through the intermeshing gear wheels 6 and 7. The ratio between the number of teeth in the two gear wheels is the same as in the example shown in Fig. 4 whereby there is rotational displacement of the actuating device in relation to the cylinder block so that it rotates in the same direction as the cylinder block but at a faster rate for the purpose of ensuring substantially a pure rolling contact between the ram ends and the face of the ram actuating device. The thrust bearing for the actuating device 5 is as in the example shown in Figs. 1, 2 and 3 in that it comprises a thrust ring 16.

In this arrangement the longitudinal axis of the cylinder block is coincidental with the longitudinal axis of the pump whilst the actuating device is disposed so that the axis about which it rotates is inclined in relation to the longitudinal axis of the cylinder block.

In both examples according to Figs. 4 and 5 the point of intersection of the axes is in the same plane as the face of the actuating device.

As will be seen upon referring to the centre lines included in Figs. 4 and 5 the point of intersection of the longitudinal axis of the ram actuating device and the longitudinal axis of the cylinder block lies in the pitch plane of the crown wheel on the cylinder block and coincides with the apex of the pitch cone of the bevel wheel of the ram actuating device. The same arrangement exists in the other examples shown and is an essential if the aforesaid rolling contact is to be obtained.

For the sake of succinctness the term "liquid" has been used throughout this Specification but as the invention is also applicable to compressors this term is also to be read as including gas wherever necessary.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. An hydraulic multi-ram pump of the type specified and in which the contacted ends of the rams or push rods are free to turn when twisted, such as by the relative motion of the ram actuating device, wherein the actuating device is connected positively to the cylinder block by toothed gearing having a tooth ratio such as will cause the part of the ram actuating device which is contacted by the rams to have a predetermined rotational displacement in relation to the cylinder block and which does not exceed the square of the secant of the angle of the face of the ram actuating device to a plane normal to the axes of the rams.

2. An hydraulic multi-ram pump of the type specified which comprises the following features to ensure substantially pure rolling contact between the ram ends and the contacted surface of the ram actuating device:—

(a) toothed gearing serving operatively to connect the actuating device to the cylinder block, consisting of a crown wheel on the cylinder block and a bevel wheel on the actuating device, the ratio of teeth in said gear connection being

equal to the secant of the angle of the ram actuating device to a plane normal to the axes of the rams so that the part of the ram actuating device which is contacted by the rams is given a predetermined rotational displacement in relation to the cylinder block, (b) the contacted ends of the rams are free to turn when twisted by the motion of the ram actuating device and (c) the parts are arranged so that the point of intersection of the axis of the ram actuating device and the axis of the cylinder block lies in the pitch plane of the crown wheel on the cylinder block and coincides with the apex of the pitch cone of the bevel wheel of the ram actuating device.

3. An axial type reciprocating pump according to any of the preceding claims comprising a cylinder block formed with a number of cylinder bores arranged around a central axis each bore having a valve controlled inlet and outlet for the liquid being pumped, a ram reciprocable and freely rotatable in each bore, a ram actuating device comprising two relatively rotatable parts, one of said parts being a power driven swash member having an inclined face and the other part being a wobbler which is contacted by the outer ends of the rams said wobbler being supported against axial thrust imposed by the rams during each delivery stroke by the inclined face of the swash member and toothed gearing having one part carried by the wobbler and the other part by the cylinder block, the number of teeth in one gear part being different from the number of teeth in the other gear part to cause the wobbler to be rotated positively relatively to the swash member but in the opposite direction.

4. An axial type reciprocating pump according to Claim 1 wherein both the cylinder block and the ram actuating device are revolved and either the cylinder block is power driven and the actuating device carried around with it by the toothed gear connection or the actuating device is power driven and the cylinder block carried around with it by the toothed gear connection, said toothed gear connection being such as to cause the actuating device to have a rotational displacement in relation to the cylinder block so that it rotates in the same direction as the cylinder block but at a faster rate.

5. An axial type reciprocating pump as in Claim 4 and in which the ram actuating device is power driven wherein the face of the ram actuating device is transverse to the axis of its rotation and the cylinder block is arranged with its axis inclined in relation to the axis of the actuating device the point of intersection of said axes being in the same plane as the face of the actuating device.

6. An axial type reciprocating pump as in Claim 4 and in which the cylinder block is power driven wherein the longitudinal axis of the cylinder block is coincidental with the longitudinal axis of the pump and the actuating device is disposed so that the axis about which it rotates is inclined in relation to the longitudinal axis of the cylinder block, the point of intersection of said axes being in the same plane as the face of the actuating device.

7. In an axial type reciprocating pump, compressor, motor or engine according to any of the preceding claims a ram actuating means comprising a driving shaft having on one end an enlarged head the forward face of which is inclined to the central axis and arranged to oppose the ends of the rams to constitute a swash member, and the rear face normal to the central axis, an annular thrust-ring disposed so as to be contacted by the rear face of the swash member to provide a bearing composed of two opposed surfaces subject to relative rotation which acts to support the same against the reaction of each ram, an annular surface for supporting the thrust ring against the said load, a bearing support for the driving shaft which permits the swash member to have a limited freedom to tilt in relation to the annular thrust ring, and means for maintaining an interposed film of oil between the opposed surfaces, said means comprising radial grooves in one of each pair of the opposed surfaces, said grooves being open at their inner ends to a space in which is available, during use, a continuous supply of oil by enclosing the ram actuating means in a casing adapted to contain a quantity of oil and by providing holes serving to connect the spaces at the inner ends of the radial grooves with the oil within the casing, the arrangement being such that the rotation of the swash member causes the oil to circulate by flowing into the said spaces and from there outwards along the radial grooves back into the casing through the outer ends of the grooves which are also open for this purpose.

8. An axial type reciprocating pump according to Claim 7 having a wobbler which is mounted so as to be free to tilt in relation to the swash member.

9. An axial type reciprocating pump as in Claim 7 wherein one of the surfaces in each bearing is formed of a soft bearing metal such as white metal and said grooves are formed in said surface.

10. An axial type reciprocating pump according to Claim 9 wherein the member having a soft metal bearing surface is rotationally stationary relative to the axial ram load.

11. An axial type reciprocating pump having a bearing according to any of Claims 7 to 10 wherein said bearing includes a washer which is faced on one side with a relatively soft bearing metal in which are cut the radial oil grooves specified in Claim 9 said washer being held to prevent the same from rotating in relation to the swash member.

12. An axial type reciprocating pump according to any of the preceding claims wherein the ram actuating device is enclosed in a casing which is maintained full of oil.

13. An axial type reciprocating pump as in Claim 12 in which a relief valve is provided to permit excess oil to escape.

14. A pump according to any of the preceding claims which is combined with a booster pump arranged so as to supply oil to the inlet manifold of the high pressure or main pump at a pressure sufficient to maintain the rams of said main pump in contact with the ram actuating device during their outward or suction stroke.

15. A reciprocating ram pump according to Claim 1, 2, or 3, having a thrust bearing which is subjected to an offset load and which consists of opposed plane and relatively rotatable surfaces which are held out of metal to metal contact by an interposed film of oil, a driving shaft rigidly associated with one of said surfaces for rotating said surface relatively to the other opposed surface, and means for supporting said driving shaft against transverse load consisting of a single journal bearing so disposed on the shaft in relation to the associated surface of the thrust bearing as to permit both the shaft and said surface to tilt in relation to the other opposed surface of the thrust bearing.

16. A reciprocating ram pump according to any of the preceding Claims 1 to 14 comprising in combination a multiplicity of rams or plungers disposed around a common axis, ram actuating means comprising a swash member, a thrust ring for supporting said swash member, and a driving shaft for said swash member, said driving shaft being supported in such manner as to permit the swash member to tilt in relation to the supporting thrust ring.

17. A reciprocating ram pump according to Claim 15 or 16 which is combined with a booster pump wherein said booster pump is driven through an extension of the main driving shaft said extension being made flexible so as to be capable of yielding to permit the main driving shaft and the swash member to tilt in relation to the other opposed surface of the thrust bearing.

18. A reciprocating ram pump according to any of the preceding claims wherein the inlet valves are of the mushroom type and arranged to oppose and almost be contacted by the inner ends of the rams at the completion of their discharge strokes.

19. A pump according to Claim 7 wherein the effect of surface flexure is minimised by supporting the thrust bearing on an annular surface having a diameter intermediate the inner and outer diameters of an annular thrust washer.

20. A pump according to Claim 7 wherein the effect of surface flexure is minimised by suitably dishing one or both of the opposed surfaces substantially as and for the purpose herein described.

21. An axial type reciprocating pump as in Claim 3, and with or without a booster pump, substantially according to the example shown in Figs. 1, 2 and 3 of the accompanying drawings.

22. An axial type reciprocating pump as in Claim 5, substantially according to the example shown in Fig. 4 of the accompanying drawings.

23. An axial type reciprocating pump as in Claim 6, substantially according to the example shown in Fig. 5 of the accompanying drawings.

Dated this 21st day of March, 1947.
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For the Applicants.

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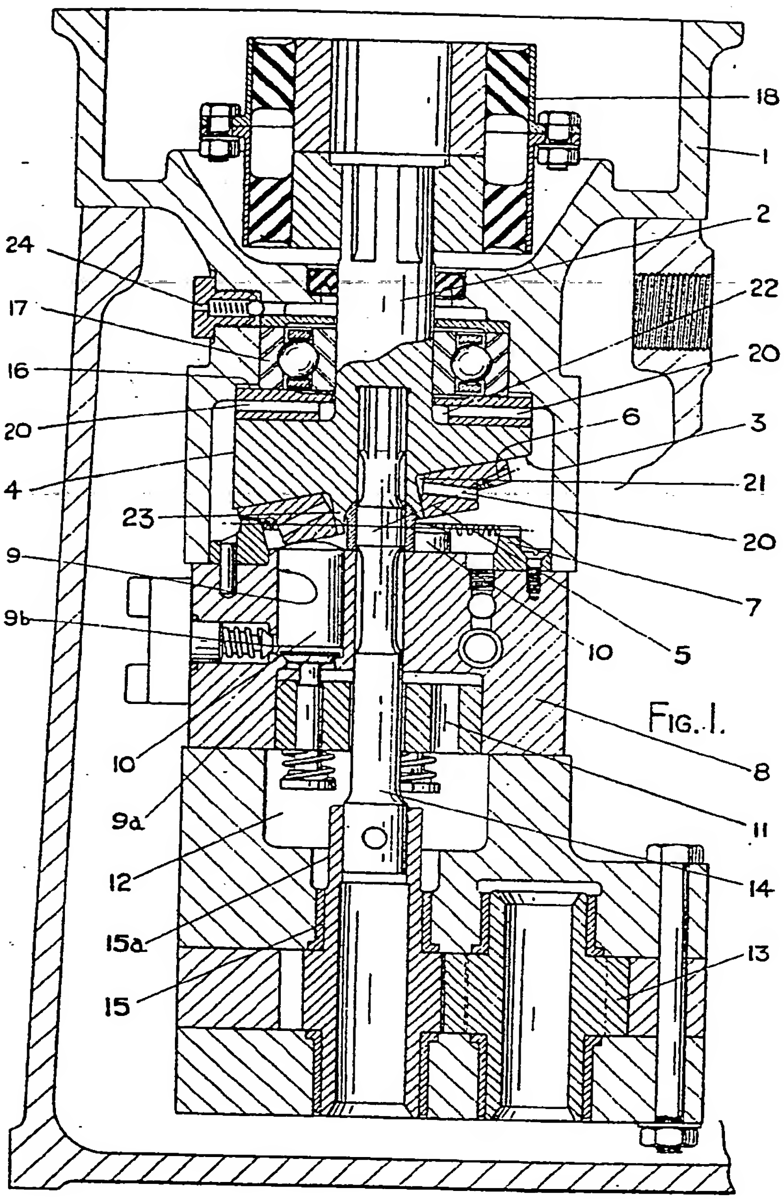
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FIG. 1.

676,612 COMPLETE SPECIFICATION
4 SHEETS

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SHEETS 1 & 2

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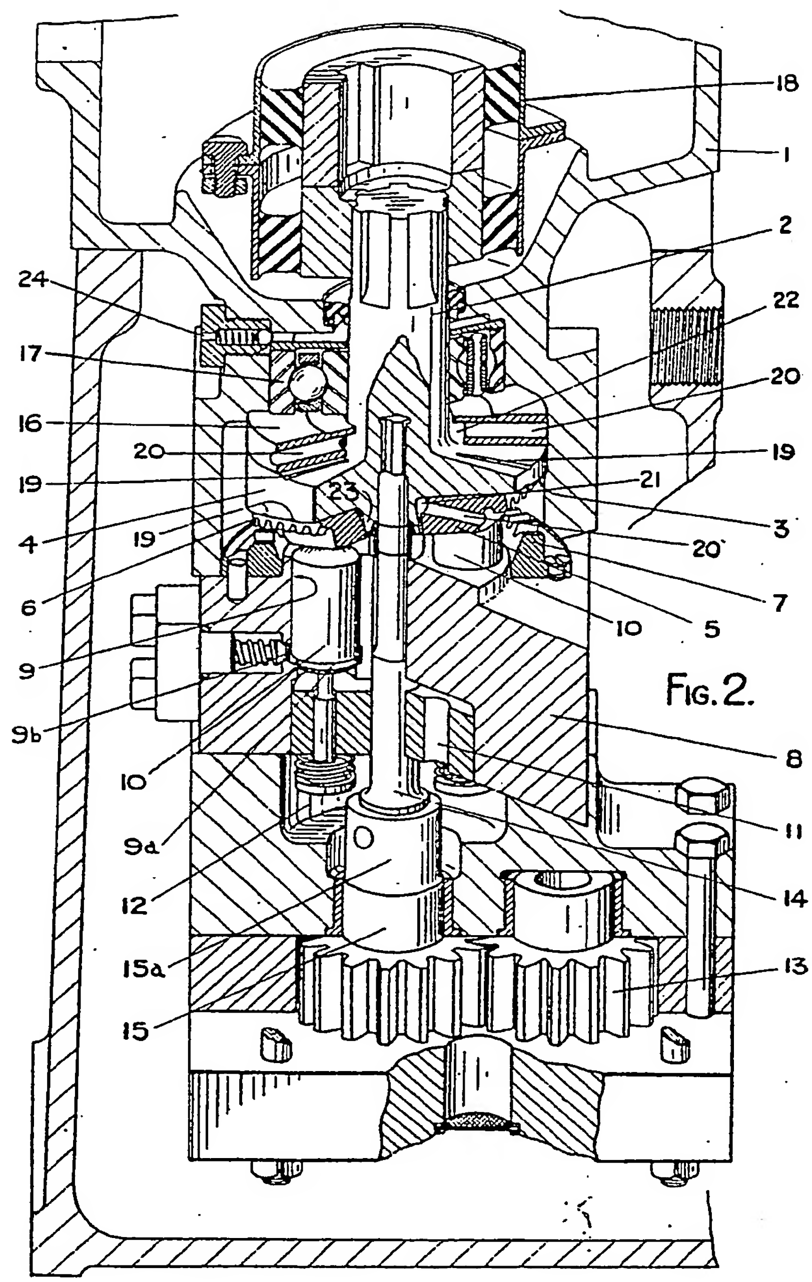

FIG. 2.

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SHEETS 1 & 2

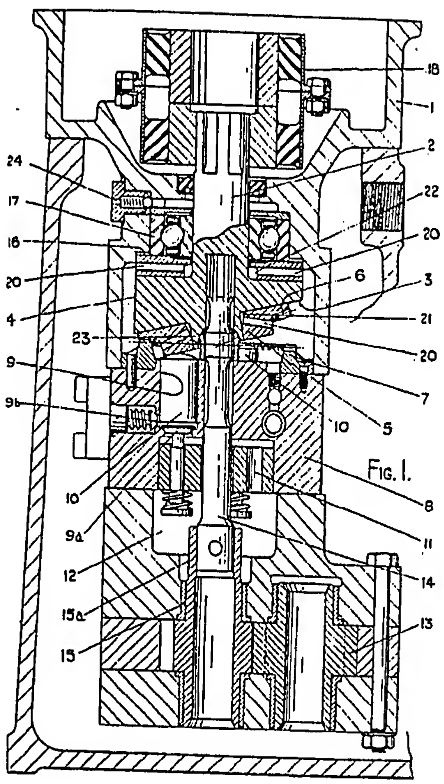

Fig. 1.

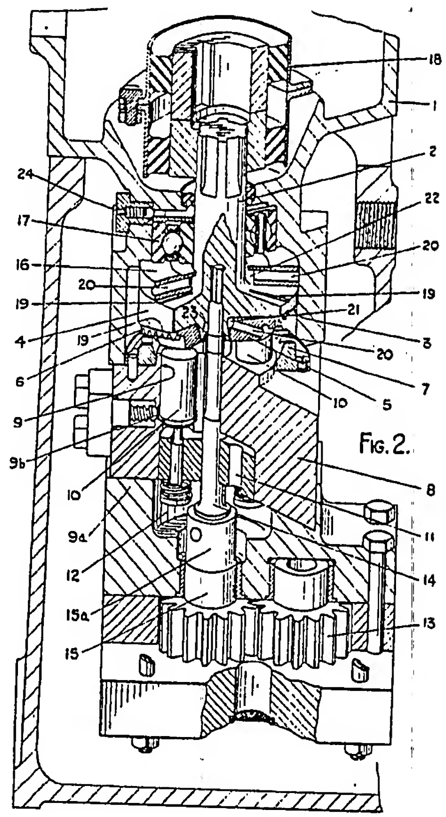

Fig. 2.

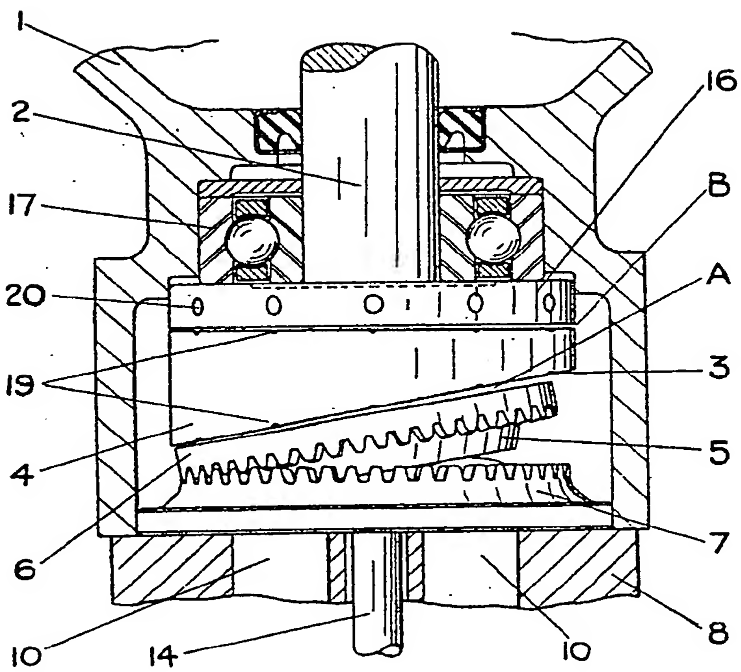

FIG. 3.

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SHEETS 3 & 4

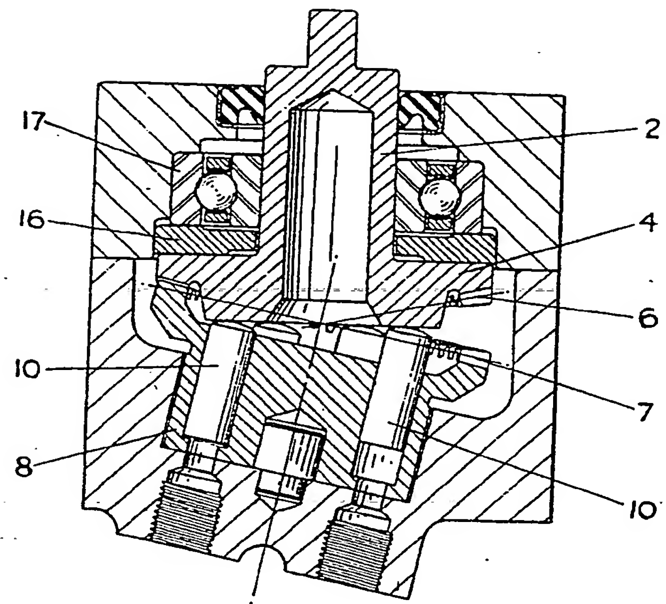

FIG. 4.

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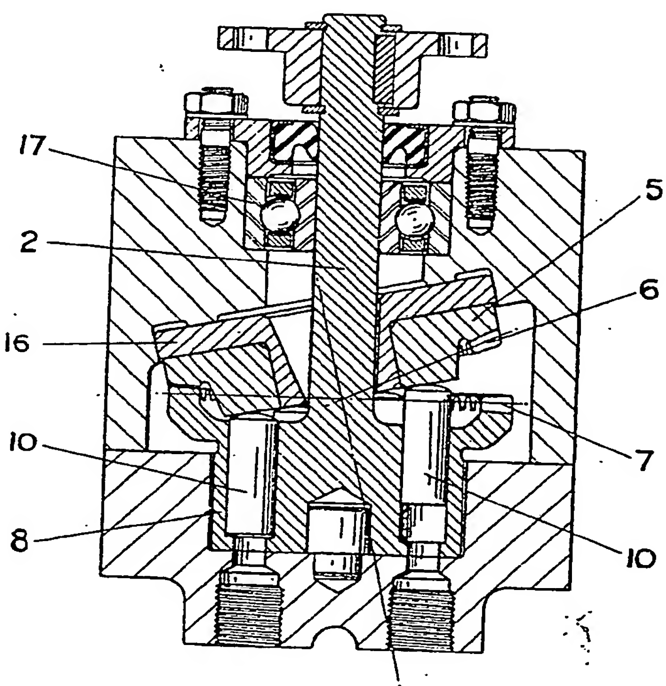

FIG. 5.

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SHEETS 3 & 4

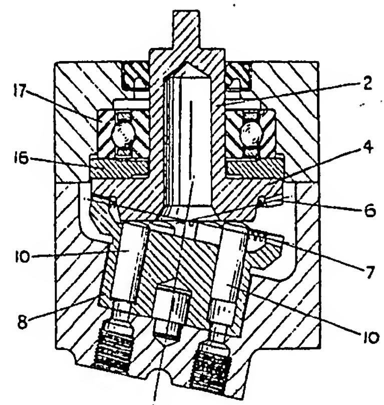

Fig. 4.

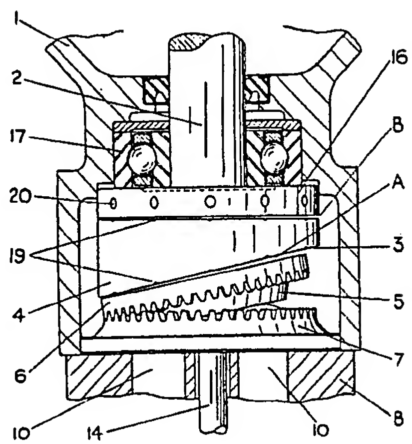

Fig. 3.

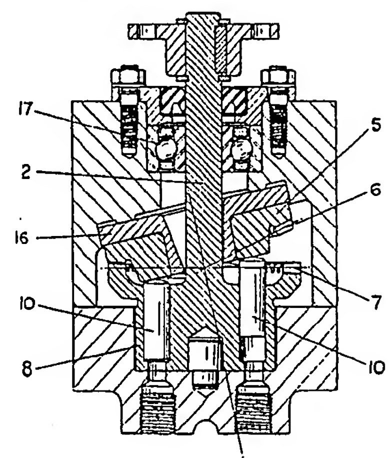

Fig. 5.